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Designing an Agent-Based Model Using Group Model Building: Application to Food Insecurity Patterns in a U.S. Midwestern Metropolitan City

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Abstract Recent advances in computing resources have increased interest in systems modeling and population health. While group model building (GMB) has been effectively applied in developing system dynamics models (SD), few studies have used GMB for developing an agent-based model (ABM). This article explores the use of a GMB approach to develop an ABM focused on food insecurity. In our GMB workshops, we modified a set of the standard GMB scripts to develop and validate an ABM in collaboration with local experts and stakeholders. Based on this experience, we learned that GMB is a useful collaborative modeling platform for modelers and community experts to address local population health issues. We also provide suggestions for increasing the use of the GMB approach to develop rigorous, useful, and validated ABMs.

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Background

Over the past few decades, systems science—an interdisciplinary approach comprehensively focusing on integrating complex elements and understanding their interactions in a system at different levels—has gained ground across diverse scientific disciplines, including but not limited to, population health, ecology, biology, and social sciences [1]. In the field of population and community health, agent-based modeling and system dynamics (SD) are among two methodologies of systems science most extensively used in research [2]. Agent-based models (ABMs) simulates the behaviors and interactions of individual agents (e.g., a person, an organization) in a responsive environment at the *individual level* for issues including but not limited to food environment, drinking behavior, influenza spread, primary care, and obesity [3–8]; in contrast, SD examines the causal links between determinants and outcomes observable at an *aggregate level* (e.g., total numbers of cancer patients in an area) for health outcomes, such as infant mortality, cancer screening, and type 2 diabetes [9–12].

Systems scientists have stressed collaboration among stakeholders to construct more realistic models, to validate the model results, and to utilize the most of model outcomes in decision making [13]. SD researchers have extensively used *group model building (GMB)*, a

participatory approach in which stakeholders from different backgrounds collaborate with other domain experts to help modelers create evidence-based models. SD modelers have incrementally developed and refined a set of GMB techniques based on experiences of conducting GMB sessions since its introduction in the early 1980s [14–16]. Such efforts resulted in a set of "scripts", which have been used by the SD community as standard guidelines to facilitate GMB sessions [17, 18].

A volume of ABM studies, especially for the topics of agriculture and natural resource management, also introduced several strategies as *companion modeling* for stakeholder involvement in model building: for example, *role-playing games (RPGs)* were used to simulate potential changes in behavior and environment under hypothetical settings using format of board games or computer simulations; another example is *backcasting*, a scenario technique with which stakeholders first define desirable future solutions or unwanted outcomes and then work backwards under current environmental settings [19–23].

However, there are few specific guidelines for using participatory processes to design ABMs in population and community health, as there are only a few studies that utilize such processes in conjunction with agent-based modeling. Homa et al. built an ABM using the GMB approach for studying inequality in health care access and utilization [3]. Rose et al. wrote an article on developing standard GMB procedures and conventions to build ABMs for the same purpose [24]. Since agent-based modeling has been often considered highly complicated to program and computationally intensive to run, ABM modelers typically have a greater role in constructing their models than stakeholders and often build their ABMs with the input of one or very few subject matter experts. This represents several inherent limitations in ABMs, such as issues of face validation, lack of uptake by stakeholders, and limited confidence in the model's inner workings. With the increased emphasis on the need for interdisciplinary approaches to address complex social determinants of health, novel approaches to collaboratively construct ABMs are needed by researchers who develop ABMs in population and community health.

Unlike the traditional approaches for developing ABMs, we adopted the GMB approach from SD for developing an ABM on food insecurity to model complexity in food environment and food shopping behaviors at the individual household level in a Midwestern metropolitan city in the USA. We took this alternative approach because food security is a complex problem and warrants cross-sector collaboration not only to fully articulate the issue but also to develop effective, sustainable solutions for addressing the underlying causes of food insecurity. GMB allows a diverse group of multidisciplinary stakeholders to collaborate on building the ABM, including the identification of key variables and the interactions between them. Further, GMB is not just a technique for defining a problem, but it can also be a catalyst for collaboration in designing appropriate and effective solutions. GMB can help participants gain an appreciation for the complexity of an issue, while also uniting them through a shared language to "connect the dots" between their disciplines [16–18]. GMB is also a process that can foster a sense of buy-in and commitment. In the long term, the GMB approach may result in establishing lasting partnerships and collaborations that may extend beyond the walls of the GMB session, into the communities impacted by these issues [2, 24]. For these reasons the research team chose GMB as a participatory research method from which to develop an ABM.

Given the nascent nature of this area of research—applying GMB best practices to ABM—it is important to not only describe the process we used to build an ABM from input received during GMB sessions, but to also evaluate the effectiveness of the GMB in eliciting appropriate information with which to build an ABM. Frerich et al. summarized the synergies in the combination of GMB and systems science in these following five categories: *paradigmatic*, *socioecological*, *capacity building*, *co-learning*, *and translational* [25]. We used these categories to evaluate our GMB approach for developing and validating the ABM.

This article aims to (1) delineate our experience with a GMB workshop to build an ABM for food insecurity, (2) reflect on what we have learned from the GMB, (3) evaluate the effectiveness of GBM for building an ABM, and (4) provide general suggestions on how future ABM studies may use the GMB approach during the model development process.

GMB Process for a Food Availability Agent-Based Model

Case Study

In the text below, we refer to the ABM that we developed to simulate each household's food availability

from its food shopping at food stores in a U.S. Midwestern metropolitan city. This case study aims to use an ABM to model complexities of the food environment and identify transformative strategies to improve human health. In our GMB workshops, we adopted the GMB scripts developed by Anderson et al. and Hovmand et al. [14, 17, 18, 25]. The following sections below describe details of each script that was used in the GMB workshops that were conducted as part of our research project. Each section below also briefly describes how insights from the group were incorporated into the various stages of development of the ABM.

Selecting GMB Participants

A wide variety of researchers, policymakers, and nongovernment organization (NGO) experts from multiple domains were involved in this research project's GMB sessions. Table 1 lists the GMB participants, their current positions/occupations, and attendance information. To select the GMB participants, we used snowball sampling; first, the research team asked *two professors* engaged in this research to recommend an initial pool of local community health and food systems experts from the prior research or outreach activities in the study area for potential collaboration; then, we made the same inquiry to *a local public health department personnel*; finally, we crosschecked those with recommended names and made the final list of individuals to invite to the GMB session. The selection of participants was based on the modeling purpose of the ABM. We then emailed the selected participants a request letter of participation with the details of the research project and the GMB process. Finally, the dates and venues for the GMB were set up using an online survey poll (e.g., Doodle and Google Forms). Writing a clear purpose for the ABM is one of the first steps in developing an ABM using GMB and, in our case, we leveraged this clear purpose to identify the most relevant GMB participants.

GMB Process

We held two GMB workshop sessions with the explicit purpose of designing a conceptual model to investigate food availability and food accessibility among households. The first GMB session was designed to help the modeling team identify the entities and state variables and to develop a framework for interactions between agents that would lead to emergent patterns at higher scales to develop an ABM. Exercises during the first GMB session, thus, were meant to achieve the following objectives: (1) defining the problem, (2) setting the model boundary, (3) outlining an estimable model that captures core structures of the system (i.e., food environment); and (4) discussing relevant policy options. The second GMB session served to identify appropriate model outputs at higher levels, clarification on simulat-

Table 1 Profiles of GMB participants and attendance at GMB sessions 1 and 2

Role	Sector	Participant profile	Attendance
Participants	Public school	Senior-level expert	Both sessions
	Public health department	Senior-level expert	Both sessions
	Public health department	Entry-level professional	Session 1
	NGO	Nationwide NGO, senior-level expert	Both sessions
	NGO	Local NGO executive	Session 1
	NGO	Local NGO researcher	Session 2
	Academic	Urban planning professor	Session 1
	Academic	Social work professor	Both sessions
	Academic	Food science professor	Session 1
	Academic	University research center researcher	Both sessions
Facilitator/Modeler	Academic	Professor in public health/modeler, facilitator, and helper	Both sessions
	Academic	Researcher in public health/modeler, facilitator, and helper	Both sessions
	Academic	Researcher in public health/facilitator and helper	Both sessions
	Academic	Research administrative coordinator/helper	Session 1

ed behaviors of agents, and face validation of the model's inner workings. The objectives of the second GMB session specifically included: (1) reviewing the processes of the first GMB session, (2) reviewing the ABM model, interpreting the analytic results, and discussing improvements that could be made to the ABM, and (3) identifying future collaborations among the participants using the final ABM. Table 2 summarizes the agenda for the two GMB workshops. These GMB agenda items were designed following the suggested procedures of Anderson et al. and Hovmand et al. [14, 16, 17]. The details of these agenda items are described in the following sections.

Hopes & Fears (Session 1)

This exercise often serves as an opening activity as an icebreaker among the participants in GMB workshops. For the exercise, participants were provided markers and two different colors of sticky notes—orange was used for hopes and magenta for fears. During the session, the lead facilitator asked each participant to write one hope and one fear per sheet. Then, each participant was asked to read one hope and one fear at a time, in a round-robin fashion. While the lead facilitator orchestrated the session and collected those sheets, other facilitators posted the hopes and fears on the white board, clustering similar ones. Finally, the lead facilitator reported the final outputs on the white board. Figure 1 and Table 3 present the outputs from the "Hopes & Fears" exercise.

Our "Hopes & Fears" responses in the GMB ranged from those focused on the GMB process (e.g. "the discussions today are engaging and lively" as a hope; "walking away with a headache" as a fear) to more outcome-oriented ones (e.g., "a data driven strategy will emerge" as a hope; "that the new political threats to American public health will not dismantle the funding or momentum to local food gained in last years" as a fear). The total amount of time allotted for this exercise was 20 min.

Table 2 The public agenda for the GMB workshops

1st GMB session	2nd GMB session
Check-in	Check-in
Introduction of participants	Welcome & Introduction
Introduction of project	Exercise 1: Review of 1st GMB
Exercise 1: Hopes & fears	Exercise 2: What we have done
Exercise 2: Identifying main barriers to food security	Exercise 3: Small group review/model exercise
Break	Break
Exercise 3: Mapping interactions	Exercise 4: Big group review/model exercise
Exercise 4: Key stakeholders	Exercise 5: Intervention Levers
Exercise 5: Intervention levers	Exercise 6: Wrap-up
Closing remarks & Adjourn	Closing remarks & Adjourn

Identifying Main Barriers (Session 1)

This script was performed after the "Hopes and Fears" script during the first GMB workshop. The objective of this script was to identify barriers that prevent households from becoming and/or staying food secure. Although ABM modelers aim to simulate every important aspect of reality in their models, it is not possible to reconstruct all components of reality. This exercise, therefore, helps participants and modelers set a priority list of variables, processes, and agents to be included in the ABM.

The GMB participants were asked the following question: "What are the barriers that prevent households from being food secure in this metropolitan area?" Each individual participant wrote one barrier per sheet, writing as many barriers as they could generate in the allotted time. The facilitator and the modeling team collected the sheets and clustered similar barriers on a whiteboard. After clustering, the participants went around to view each other's answers and voted on important barriers using dot stickers; each participant was provided with five stickers.

Figure 2 and Table 4 illustrate the outputs from "Identifying Main Barriers" script. Our participants reported over 50 barriers to household food security in the GMB workshop. Then, the facilitators grouped the barriers into 11 categories and participants voted on the most important ones. The categories that the GMB participants most frequently voted for included "household income & income stability," "structural/institutional inequalities," "policy, advocacy & access in the food system," and "inequities in food policies." It took 40 min to complete this script in our GMB session.

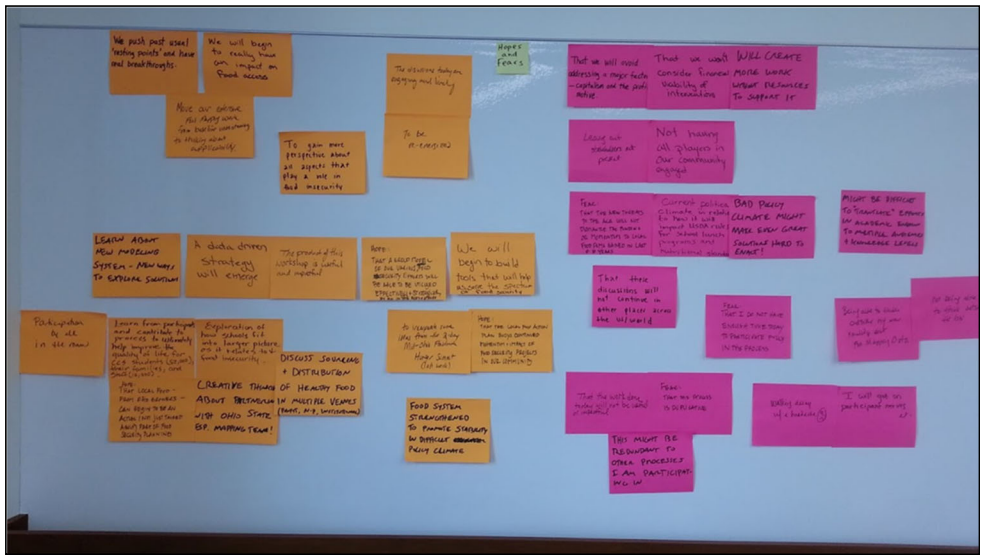


Fig. 1 Hopes (orange) & Fears (magenta) identified by the GMB participants

Mapping Interactions (Session 1)

Mapping interactions was the third exercise performed at the first GMB workshop. For modelers, this session was the most important to compare their mental model with those of the participants. The objective of this exercise was to identify the underlying factors and household characteristics that were associated with each selected barrier to food security.

At the beginning of the session, a modeler explained the details of the research project—i.e., the geographic study area, the prior research activities, the preliminary datasets, and potential components in our ABM such as agents (e.g., households, food stores),

Table 3 Summary of hopes and fears Identified by the GMB Participants

Hopes	Fears
• We push past usual 'resting points' and have real breakthroughs.	• That we will avoid addressing a major factor – capitalism and profit motive.
• We will begin to really have an impact on food access.	• Not having all players in our community engaged.
• To gain more perspective about all aspects that play a role in food insecurity.	• Bad policy climate might make even great solutions hard to enact.
• The discussions today are engaging and lively. • To be re-energized.	• Might be difficult to translate efforts in academic environment to multiple audiences and knowledge levels.
• Learn about new modeling system & new ways to explore solutions.	• That these discussions will not continue in other places across the U.S./world.
• A data driven strategy will emerge. • The product of this workshop is useful and impactful. • That a group model of our various food security efforts will be able to be utilized effectively and strategically by all in the room and others.	• That I do not have enough time today to participate fully in this process. • Being able to think outside my own knowledge. • Not being able to think outside the box. • That the work done today will not be useful or impactful.
• We will begin to build tools that will help us serve the spectrum of food security. • Participation by all in the room. • Exploration of how schools fit into larger picture as it relates to low food insecurity. • Discuss sourcing and distribution of healthy food in multiple views.	• That this process is duplicative. • Walking away with a headache. • I will get on participant's nervous. • This might be redundant to other processes I am participating in. • That we won't consider financial viability of interventions.

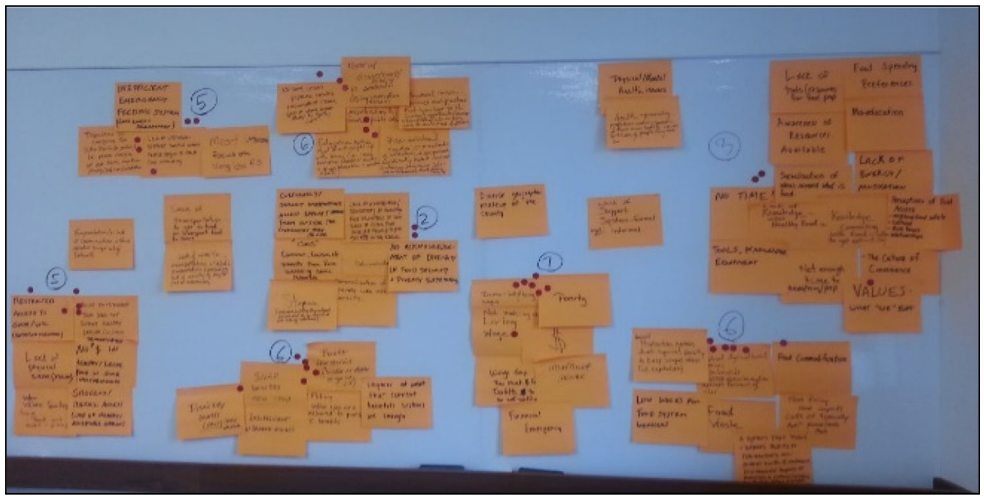


Fig. 2 Main barriers identified by the GMB participants

parameters (e.g., the distance to food stores, household income, the variety of food items available at each store), and behavioral rules (e.g., the frequency of shopping, the preference to specific food store types). The modeler also presented a "toy model," which was a simplified conceptual model of food insecurity built using AnyLogic 7, a software package for ABMs [26]. Then, participants were asked to self-select into two groups, and each group was asked to create their own conceptual model by mapping the interactions (by drawing on a whiteboard) between important factors leading to food insecurity at the household level. After finishing the mapping exercise, each group had a chance to explain their conceptual model to the other group. Participants also could freely ask and answer questions about the model with other participants. The groups were initially divided up and reconvened in order to encourage divergent thinking, to build a stronger, more comprehensive model. Figures 3, 4, and 5 show the conceptual models designed at the first GMB, and their electronic versions. The total time spent for this session was 45 min.

Key Stakeholders (Session 1)

This script was performed during the last session during the first GMB workshop. The purpose of this script was to identify those key stakeholders, particularly in consideration of who might be able to address the barriers to food security that participants identified earlier in the workshop.

Participants were asked to identify as many stakeholders as they could think of using the sticky notes (one stakeholder per sticky note). Then, the facilitators placed the sticky notes of each key stakeholder on the whiteboard marked with a horizontal-vertical plane indicating

Table 4 Groups of main barriers identified by the GMB participants

Rank by vote	Main barriers	Number of votes
1	Household income/income stability	7
2	Structural/institutional inequalities	6
2	Policy, advocacy & access in the food system	6
2	Inequities in food policies	6
5	System integration & sustainability	5
5	Barriers to physical access to foods	5
7	Individual behaviors, preferences, & knowledge	3
8	Shaming & blaming	2
9	Physical/mental health factors	0
9	Lack of support (formal/informal)	0
9	Diverse geographic makeup of the county	0

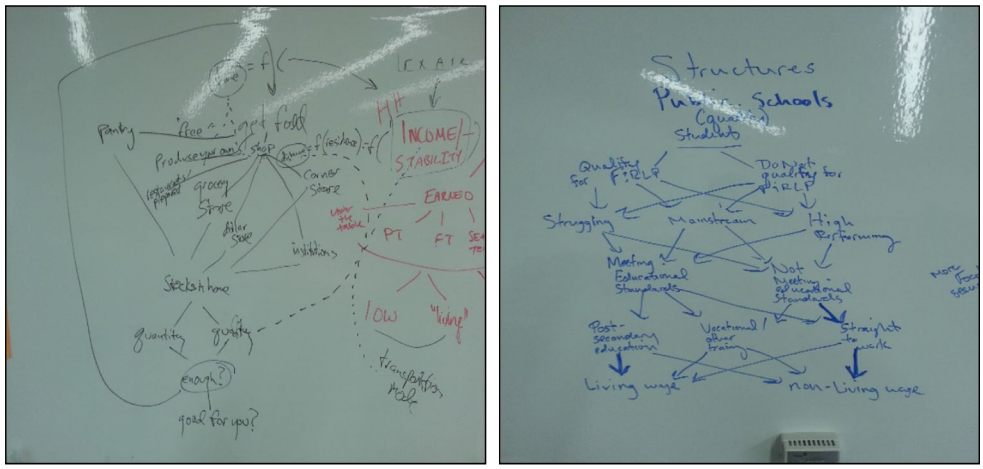


Fig. 3 Conceptual models drawn by the participants at the first GMB

levels of interest and power (low to high), respectively. Figure 6 shows the key stakeholder graphs identified by the GMB participants. Some notable responses include "Me (High Level of Interest-Low Level of Power)," "Philanthropists (Mid Level of Interest-Mid Level of Power)," "Federal public health departments and agencies (Mid Level of Interest-High Level of Power)," and "Non-profit foundations (High Level of Interest-High Level of Power)." This exercise lasted 30 min.

Intervention Levers (Session 2)

This exercise was originally set up for the first GBM but alternatively performed in the second GMB because of time shortage. The aim of this exercise was to identify intervention levers that key stakeholders could implement to reduce/remove barriers to food insecurity. The participants were instructed to write one intervention per sheet/sticky note, generating as many as they could during the allotted time. Facilitators then posted the sticky notes on a whiteboard. Next, the GMB participants were again given five dot stickers to vote on the most important intervention levers. The reported intervention levers were integrated into the final analysis model as "What if?" policy scenarios for reducing the rate of food insecurity. The total time spent for this session was 20 min.

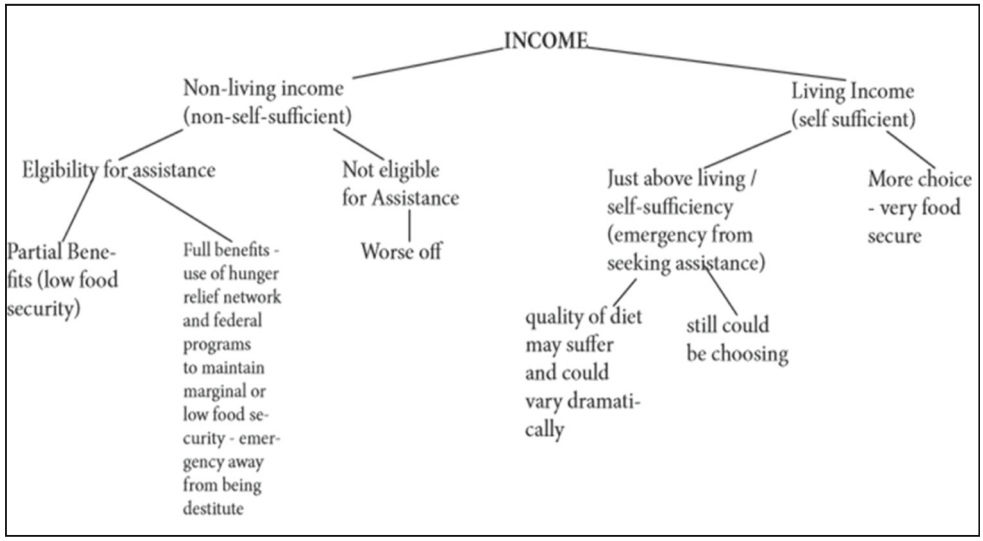


Fig. 4 Conceptual model 1

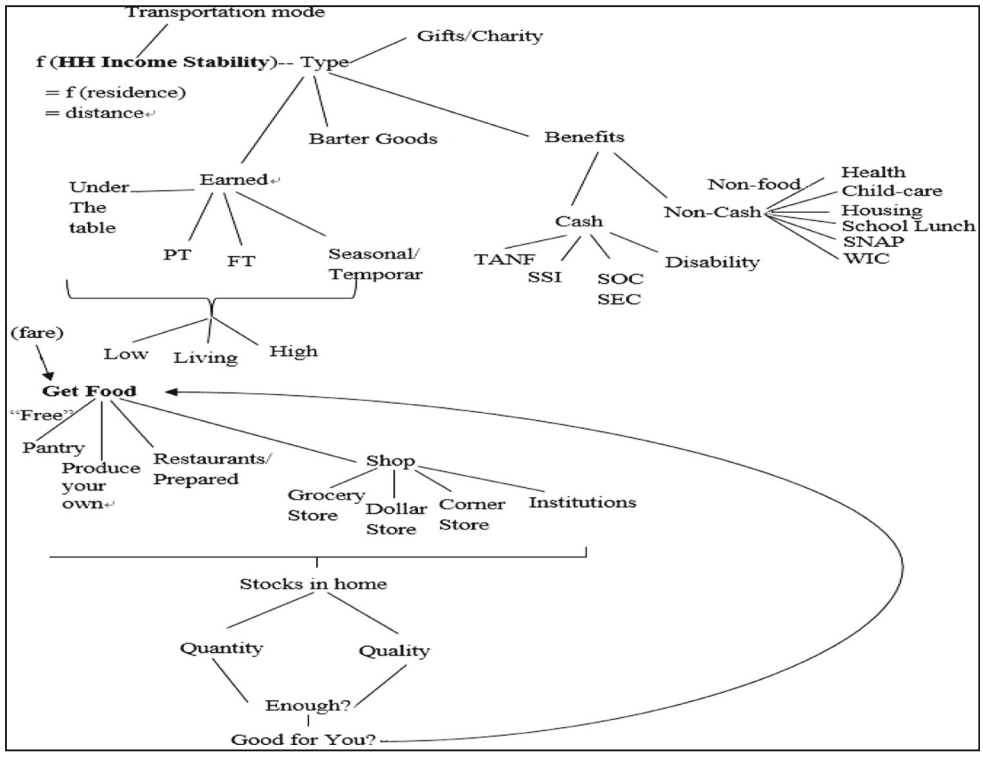
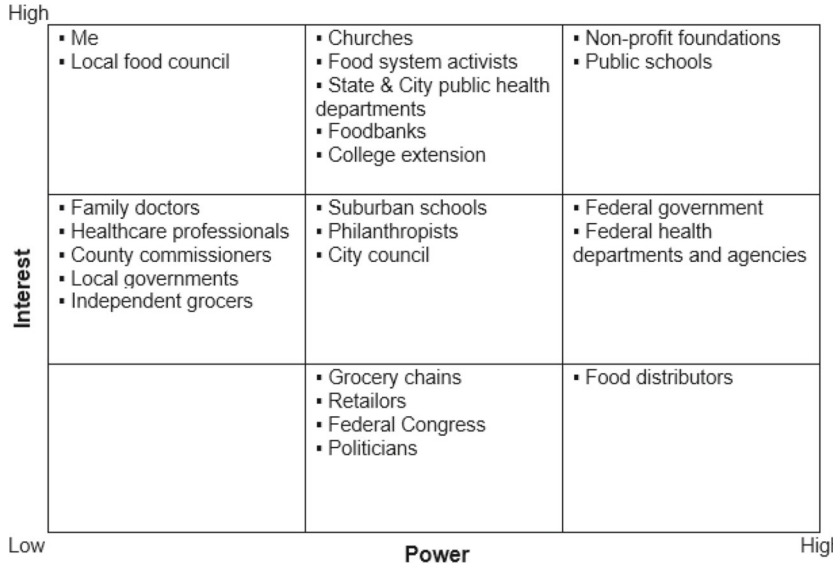


Fig. 5 Conceptual model 2

Validating Models (Session 2)

This exercise was the most essential part in our second GMB workshop. The purpose of this exercise was to obtain feedback from the participants on a near-final version of the ABM (Fig. 7). At the beginning of the session, a modeler presented the GMB participants the near-final version of the ABM. The modeler explained

Fig. 6 Key stakeholders illustrated by the GMB participants on the plane of the interest-power levels



Note: Specific organization names intentionally concealed by the authors for sensitivity.

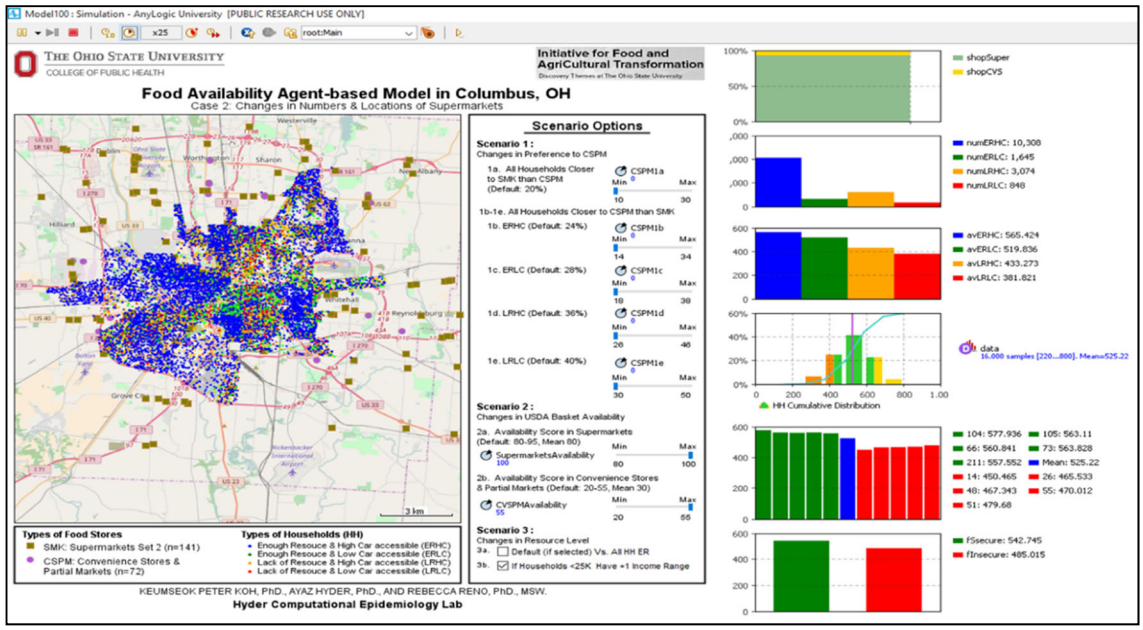


Fig. 7 A screenshot of a tentative ABM created in AnyLogic 7

to the participants how the modeling team incorporated the two conceptual models previously designed by the GMB participants at the first GMB workshop into the model also following the general guidelines for model building from the literature [27] (Figs. 3, 4, and 5). Then, the participants were randomly divided into two groups to review the details of the model. The modelers asked them (1) how similar the food shopping behaviors of households in the model were to the real-world setting, (2) how relevant the policy scenarios were to the participants' organizational objectives and goals, and (3) how useful the layout of the web-based application version of the model was. This was critical because an explicit goal in developing the ABM was to ensure that the model was useful to participants and their organizations who would utilize the model in their efforts to reduce food insecurity, moving forward. The participants used a large whiteboard to redraw the conceptual models and provided feedback. The modelers collected each group's reviews through written notes and pictures. Then, all participants came back together as a larger group to discuss each group's comments on the model. At the end of this exercise, the modelers notified the GMB participants that all the material used in the GMB workshops and the final ABM model would be accessible via an online cloud service (e.g., Dropbox) and a website (www.runthemodel.com) after developing the final ABM. We allotted 50 min for this exercise, but ended up spending 1 h and 30 min to finish the session (Fig. 8).

Discussions

Lessons from the GMB

This study seeks to not only describe the process of using GMB for ABM, but to also provide some preliminary evidence regarding its effectiveness. The five categories of synergies between GBM and systems science, aforementioned, were used, as they provide an organizing framework through which the utility of GMB for ABM can be categorized [25].

Our research harnessed *paradigmatic synergy* through GMB sessions, in order to create a validated ABM that integrates the knowledge of both scholars and practitioners. While our ABM utilized multiple sources of data to simulate the most plausible behaviors and characteristics of the agents in reality, it also used the GMB participants' a priori knowledge built from their experiences, beliefs, and philosophies. This theoretical framework is different from traditional research approaches in population health, which heavily rely on reductionist, positivist paradigms in scientific thinking, which stress a posteriori knowledge and rigorous

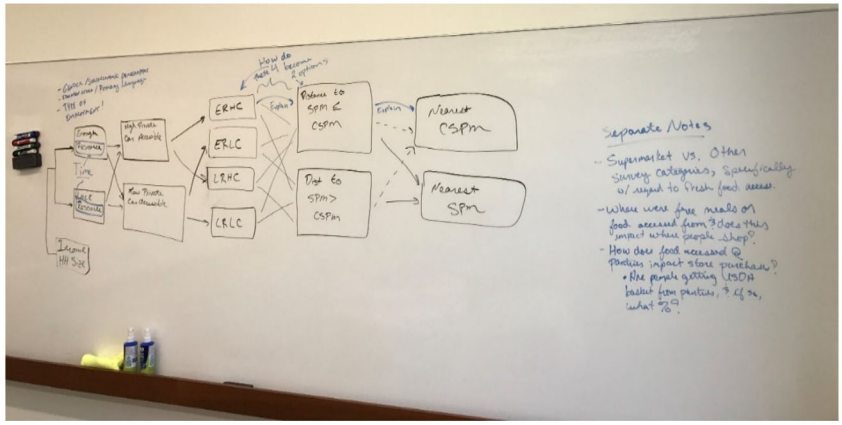


Fig. 8 A review of the conceptual model co-created by the modelers and the participants

quantitative analysis on the causal associations between causes and effects [25].

Second, our approach demonstrated *socioecological synergy* by using the GMB approach to build an ABM. Our ABM aimed to simultaneously model multi-level factors of food insecurity including population demographics, food store locations and types, transportation options, geography, and impact of policies. The diversity in the GMB participants, in terms of the variety of domain expertise, levels of positions, preference in research methods, and sociodemographic backgrounds, helped us to create an ABM from a holistic perspective via the GMB approach. The GMB also helped us strengthen the face validation of the final ABM, which enabled the modelers to have confidence in the final outputs.

Third, our GMB workshops demonstrated that agent-based modeling and GMB work together to achieve *capacity-building synergy* in a community. Public health capacity-building in a community is defined as its efforts to cultivate and accumulate relevant knowledge, abilities, systems, and resources to address public health-related problems and challenges [28]. We could identify the GMB sessions as a good platform to build additional community capacity to address food insecurity in our study area in the present and the future through collaborations with stakeholders.

Fourth, we found that utilizing the GMB process for agent-based model building can bring *co-learning synergy* to modelers and to GMB participants. While modelers can learn more about the real world to incorporate into their models, the GMB participants can gain knowledge about the potential of systems science approaches and participate in research processes. Such co-learning synergy can help both modelers and GMB participants gain a common ground in research and community engagement through interactive processes between modelers and stakeholders to accumulate new information and perspectives and to modify their way of thinking [29].

Finally, the *translational synergy* was obtained in the combination of GMB and agent-based modeling. When modelers aim to provide effective solutions to real world problems to communities, GMB participants can help modelers have a most realistic sense of the world. In addition, GMB participants can apply the findings of agent-based modeling approaches to other community engagement efforts and policy interventions. For example, the policy scenarios used in the ABM generated through the GMB workshops, were based on the local food action plan designed by local experts and stakeholders. The ABM in this study also evaluated the impact of the recent supermarkets' closings on food accessibility, which was a major concern among the GMB participants.

Suggestions for Using GMB for ABM

For future applications of using a GMB approach to develop ABMs, we suggest the following based on our experiences. First, it is important to engage participants with a wide range of experience and expertise in the GMB sessions. We suggest conducting a preliminary literature review and engaging local experts to ensure that adequate representation across stakeholders is achieved.

Second, the outputs from GMB participants and other relevant documents should be provided to participants as soon as possible after each GMB workshop. It would be beneficial to have an appropriate platform to share the findings and results of the GMB sessions and the ABM, for better communication with participants using

an online cloud service (e.g., Dropbox), online survey tool (e.g., Google Forms, Doodle), and website to report progress in project.

Third, effective facilitation will determine the quality of GMB session. We recommend each session is led by at least two facilitators. The *process-oriented facilitator* should serve as the main host, leading participants through each exercise, ensuring the session is following the predetermined timeline and asking probing and clarifying questions, as necessary. In contrast, Considering and addressing logistical concerns is the primary role of the *content-oriented facilitator*, who should have advanced ABM expertise. Their role is to help guide conversations towards model development, particularly in the latter portion of the process.

Of utmost importance, it is necessary to develop standard boundary objects and scripts facilitating GMB workshops for use in building ABMs. Modifying the scripts used in the field of SD modeling is an ad hoc strategy for developing an ABM using the GMB approach. The GMB scripts are helpful tools to create conceptual models. However, in the long term, establishing specific scripts for building ABMs is necessary because the scale of analysis between a SD model (i.e., for aggregate level) and an ABM (i.e., for individual level) are different from each other. Alternatively, ABM researchers can adopt essential components from the aforementioned participatory modeling building strategies in the agriculture and natural resource management literature [19–23]. However, it requires substantial modifications or adjustments in use for public health studies: for example, while RPGs were useful to capture immediate interest between stakeholders (e.g., the conflict in water use between farmers in a remote area), their use may be limited in the domain of public health (e.g., food security is an important public issue for food-insecure households and public health departments but may not for retail food stores to involve in). Backcasting technique is also criticized that it may not fully capture ongoing changes in environment at present [19–23].

Limitations

We recognize several limitations in the use of GMB for ABM development. First, the different levels of interest and experience in ABM among participants may limit the effectiveness of GMB sessions. Presenting examples of similar models in the initial portion of GMB sessions helps address this limitation, although the content-oriented facilitator will likely need to dedicate time throughout the GMB sessions to clarify what an ABM is, what it is capable of capturing, and to identify some of its limitations (e.g., data availability). Second, participants often have varied levels of expectations from the GMB session. It is very important to clarify the goals and objectives of the GMB session to the participants in the preparation stage, since there are other, similar types of group activities that are designed to share knowledge and develop a network, but not to build ABMs. Third, there may exist challenges in translating the GMB participants' conceptual models into the actual ABM, especially due to data availability and/or technical difficulty. Thus, it is important to set relevant model boundary or technicality in modeling among participants. Finally, participants should have a shared, clear agreement on the authorship or ownership of the ABM, the general use of the ABM, and future collaboration opportunities [24]. This is best established by explicit conversations upfront and periodic check-ins, to set expectations and address any concerns or questions that arise.

Conclusion

This article describes our experience regarding using GMB sessions to build an ABM focused on food insecurity. We have learned that GMB is an effective method for modelers and community experts to collaborate and to address local population health issues. We discussed the details of several standard scripts utilized in our GMB, which were adapted from the SD community. We encourage other ABM developers to utilize GMB sessions in future studies since there are multiple synergies achievable by using GMB sessions with ABM. We also anticipate and encourage additional studies to develop standard boundary objects and scripts facilitating GMB sessions to design valid and representative ABMs.

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